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A procedure for testing padding materials in fruit packing lines

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Summary:

Padding materials are commonly used in fruit packing lines with the objective of diminishing impact damage in postharvest handling.
Two sensors, instrumented sphere IS 100 and impact tester, have been compared to analyze the performance of six different padding materials used in Spanish fruit packing lines. Padding materials tested have been classified according to their capability to decrease impact intensities inflicted to fruit in packing lines.
A procedure to test padding materials has been developed for "Golden" apples. Its basis is a logistic regression to predict bruise probability in fruit. The model combines two kinds of parameters: padding material parameters measured with IS, and fruit properties.

A procedure for testing padding materials in fruit packing lines

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1. Introduction

Fresh fruits and vegetables suffer impacts as they are mechanically handled in commercial packing lines. Impacts commonly occur when the product is transferred between successive elements (transfer point) in the line.
Bruise onset is induced when the failure stress or the maximum deformation for the product tissue are exceeded (depending upon the damage mechanism). Bruise onset and magnitude depend on different factors: height of the transfer points, working velocity, hardness of the surfaces, curvature of the surfaces, and fruit characteristics (mass, curvature, temperature, humidity, firmness,), etc.
Damage can be diminished or avoided by locating padding materials on the surfaces of the machines (Burkner et al., 1972). A good padding material must satisfy three requirements (Bollen et al., 1995): 1. It must absorb the impact energy without damaging the product. 2. It should not apply a high rebound energy to the produce, and should avoid fruit-fruit impacts. 3. It must be durable and compatible with packing line conditions (no toxic, no absorption of dirt, etc.).
The choice of a padding materials must be such that the most bruise sensitive items may be handled without damage. Some studies have been carried out to establish evaluation procedures of padding materials (Bollen et al., 1995) with limited success.
Padding materials can be tested on the packing lines or in laboratory tests. Whenever a test allows a proper evaluation for simplifying the choice of a padding material, it will be preferable than on-line testing.
Traditional tests (eg. ASTM static stiffness) used to evaluate properties of foam materials, can not be applied in the case of dynamic impacts (Armstrong et al., 1995). The instrumented sphere (IS) (Zapp et al., 1990) is a good tool for establishing dynamic characteristics of any padding material by means of its triaxial accelerometer (Bollen et al., 1995; Miller, 1998; Schulte et al., 1992). Another different sensor, an impact tester composed by a spherical steel mass with an uniaxial accelerometer on top (Chen et al., 1985; Jarén et al., 1992) can be used with the same goal.

2. Objective

The objective of the study was to develop an evaluation procedure of padding materials commonly used in fruit and vegetable packing lines.

3. Materials and methods

An instrumented sphere IS 100 (161 g mass and 70 mm diameter; triaxial accelerometer) and an impact tester consisting of a spherical falling mass with an uniaxial accelerometer attached (50 g mass and 19.5 mm diameter) have been used to test six padding materials commonly used in Spanish fruit packing lines. Padding materials properties are shown in Table 1.

Table 1. Padding materials characteristics.

Material	*Designation*	*Thickness, mm*
Polyester with polythene	A	4
PVC with polythene	B	5
Polythene	C	5
Polythene	D	10
Urethane	E	5
Polythene	F	10

Several tests have been carried out with two goals: 1. Studying the performance of both sensors (IS and impact tester) to classify padding materials according to maximum acceleration reduction. 2. Obtention of a statistical model, applied to "Golden" apples, to predict probability of damage based on the characteristics of the padding materials. This study would allow the choice of the specific padding material as a function of each particular product.

3.1. *Sensors evaluation*

A specific test was developed to study the effectiveness of IS and impact tester to classify the padding materials. IS and impact tester were dropped at different heights, 4, 8, 12, 16, and 20 cm, onto four padding materials: A, B, C, and D. For each combination ten measures were taken. Data supplied by the sensors were recorded in computer files.

3.2. *Padding materials classification*

Once both sensors (IS and impact tester), were studied, new measurements were taken with the IS for the six padding materials (A, B, C, D, E, and F) at different dropping heights: 4, 8, 12, 16, 20, 24, and 28 cm.. These measurements were used to classify the materials according to the impact intensity (the higher the impact intensity the lower the impact reduction), and to develop a statistical model to predict damage in "Golden" apples.

3.3. *Assessing bruise probability for "Golden" apples*

Two groups of "Golden" apples were impacted as follows:

First experiment: A total of 168 apples of four sizes (1, 2, 3 , and 4) were divided in groups of four apples (one of each size). Impacts were produced onto the six padding materials at seven dropping heights: 4, 8, 12, 16, 20, 24, and 28 cm. For each padding material and height a group of four apples was impacted.

Second experiment: 480 apples (240 of size 1 and 240 of size 3) were divided in groups of 30. Each group gathering apples of the same size. Impacts were produced onto padding materials B and C at four dropping heights: 4, 12, 20, and 28 cm.

Bruises onset was checked after 24 h at ambient conditions, and its area was measured.

A logistic regression was computed based on the following variables: a) occurrence of damage in a pool of 168 apples of the first experiment and in 40 apples of the second experiment. These 40 apples had the following characteristics: both sizes 1 and 3, both padding materials B and C, and extreme heights (4 and 28 cm); b) apple mass; c) maximum acceleration obtained with IS; d) velocity change obtained with IS.
The obtention of damaged apples in the total range of probability (0-1) is really difficult and unreal, furthermore, working with few fruits in the extremes, an error in the bruise onset could modify wrongly the logistic regression. To avoid this problem, the number of apples belonging to extreme heights (4 and 28 cm), chosen to compute the model was larger (44 apples for each extreme height) than for medium heights (24 apples for each height). The logistic regression calculated was validated with 440 apples belonging to the second experiment, and not used for the regression computation.

4. Results and discussion

4.1. *Sensors evaluation*
Both sensors, IS and impact tester, were able of classifying the different padding materials according to the impact intensity.

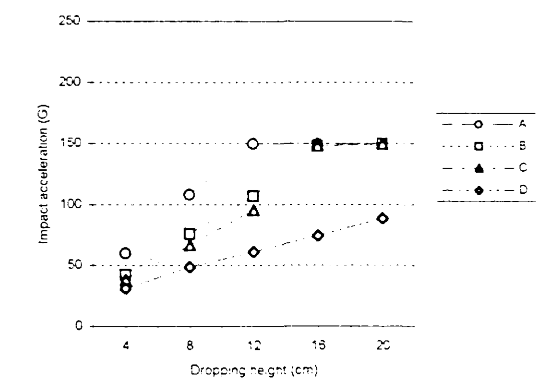

Figure 1. Acceleration values obtained with the impact tester.

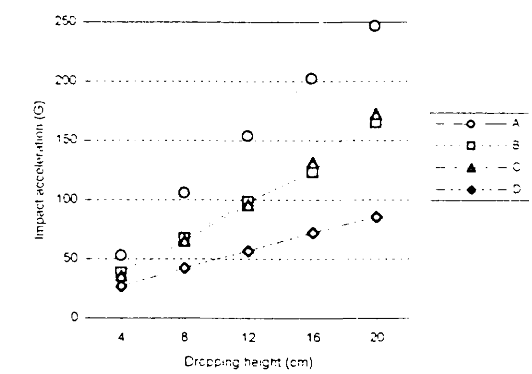

Figure 2. Acceleration values obtained with the instrumented sphere (IS).

Table 2. Average values and standard deviation for each test.

			Average Values (G)		Standard deviation (G)	
Materials	Designation	H(cm)	Impact tester	IS	Impact tester	IS
Polyester-Polythene 4mm	A	4	60	53	0.65	3.97
PVC-Polythene 5mm	B	4	42	39	1.19	0.83
Polythene 5mm	C	4	38	36	0.86	1.25
Polythene 10mm	D	4	31	27	0.85	1.23
Polyester-Polythene 4mm	A	8	108	106	0.76	1.23
PVC-Polythene 5mm	B	8	76	67	0.97	2.30
Polythene 5mm	C	8	67	65	2.06	1.80
Polythene 10mm	D	8	49	43	1.15	1.65
PVC-Polythene 5mm	B	12	107	99	1.51	1.7
Polythene 5mm	C	12	96	96	2.33	2.42
Polythene 10mm	D	12	61	57	3.15	5.29
Polythene 10mm	D	16	74	72	1.33	2.03
Polythene 10mm	D	20	89	86	2.45	2.51

Figures 1 & 2 show the maximum acceleration data obtained with the IS and the impact tester for each padding material and dropping height. Each impact data is reported in average peak acceleration (n = 10) of gravity units (*G*), where 1G = 9.8 m/s^2.
Table 2 shows data of average values and standard deviation of each test. It must be taken in mind that the maximum acceleration value registered by the impact tester accelerometer is 150 G, values above 150 G are not considered.
Results are very similar with both devices (Table 2). Results in Table 1 point out the following findings: the average peak acceleration with the impact tester is slightly higher than with the instrumented sphere (slight lack of reproducibility between sensors), and the standard deviation of tests with the impact tester is smaller when compared to those developed with the instrumented sphere.
The first result can be the consequence from the fact that the plastic material of the instrumented sphere has a higher cushioning power than the steel of the impact tester. The second finding could be because the instrumented sphere has some lack of homogeneity.
The use of the impact tester is appropriate for accurate measures in laboratory because of its larger repeatability and easier handling in relation to the IS.

4.2. *Padding materials classification*
Since, under the present configuration, the uniaxial impact prototype has an upper limit of 150 G (half of IS100 upper limit), IS data parameters (maximum acceleration and velocity change) were used to classify padding materials (*Figure 3*).
In general the more effective the padding material, the flatter the curve is (closer to the velocity change axis). Padding material F is the most effective, and padding material A the less effective. For a specific dropping height, the maximum acceleration values are really different in function of the padding material tested.

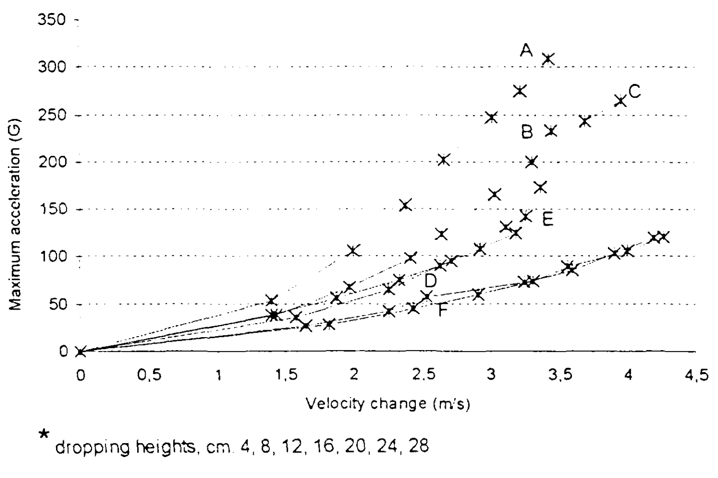

Figure 3. IS impact responses for padding materials.

4.3. *Statistical model*
A logistic regression to estimate bruise probability for "Golden" apples was computed (as is described in point 3.3), based on the following variables: apple mass (*m*), IS

maximum acceleration (G), and IS velocity change (vc). The statistical model (*Figure 4*) predicts the bruise probability according to this equation:

$$\textit{Bruise probability}(\%) = \frac{e^f}{1+e^f} \cdot 100 ; \qquad \text{being,} \quad f = \mathrm{a} + \mathrm{b} \cdot m + \mathrm{c} \cdot G + \mathrm{d} \cdot vc ;$$

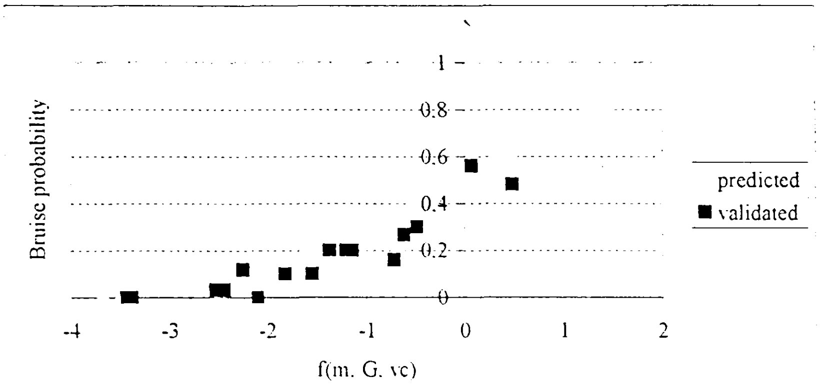

Figure 4. Logistic regression to predict bruise probability in "Golden" apples.

The model, computed with 208 apples and validated with 440 apples, predicts bruise probability correctly, with unexplained variance of 0.104 ($r^2 = 0.896$).
The lower amount of fruits (208 vs 480) used for the logistic approach to bruise prediction does not increase the confidence band (5% aprox. for bruise prediction values, below 10% EU tolerance) when compared with bruise prediction by means of nested groups of individuals (8% aprox.)
The use of this model is useful to establish the conditions for the acceptance of a padding material.

5. Conclusions

- ✓ Instrumented sphere IS and impact tester can be used to test the performance of padding materials to reduce impact intensities on fruit. Impact tester is more precise compared to IS, but its upper limit of the maximum acceleration value is lower, limiting its use to test padding material at harmful conditions.
- ✓ A procedure for testing padding materials in fruit packing lines based on a logistic regression computed with two kind of parameters, padding materials characteristics measured with IS and fruit characteristics, has been developed and tested successfully for "Golden" apples.
- ✓ The procedure proposed reduces the number of fruits necessary to accept a padding material compared to traditional methods.

6. Acknowledgements

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